Radiological Terminology and Units

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INTRODUCTION

This module will provide you with information about four different types of ionizing radiation: alpha, beta, gamma, and neutron. Radiological terminology used in the transport of radioactive material and radioactive waste will be defined and discussed. This module also identifies the different units used for measuring radiation and radioactivity.

PURPOSE

The purpose of this module is to increase your knowledge of ionizing radiation. Knowing the terminology and measuring units associated with radioactive material will help you communicate more effectively with assisting agencies while responding to an incident involving radioactive material.

MODULE OBJECTIVES

Upon completion of this module, you will be able to:

1. Identify four basic types of ionizing radiation.
2. Identify the terms used to measure radiation and radioactivity.
3. Identify terminology and acronyms associated with shipments of radioactive material.
4. Define transuranic waste, low-level waste, high-level waste, and mixed waste.
5. Identify commonly used Proper Shipping Names for radioactive material.

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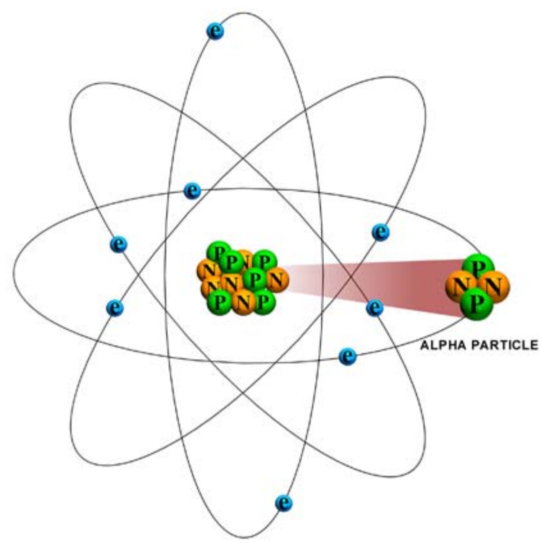
THE FOUR BASIC TYPES OF IONIZING RADIATION

Most of the commonly transported radioactive materials emit one or more forms of ionizing radiation. The four basic types of ionizing radiation are alpha radiation, beta radiation, gamma radiation, and neutron radiation. All four types differ in their penetrating power and the manner in which they affect human tissue. To give you a general understanding of each type, they are discussed here.

Alpha



Alpha radiation consists of high-energy particles that are relatively large, heavy, and only travel a short distance. Because they are so large and heavy, alpha particles lose their energy very rapidly, have a low penetrating ability, and short range of travel—only a few inches in air. Because of the alpha particle's short range and limited penetrating ability, external shielding is not required. A few inches of air, a sheet of paper, or the dead (outer) layer of skin that surrounds our body easily stops alpha particles. Alpha radiation poses minimal biological hazard outside the body. The greatest hazard from alpha-emitting material occurs when the material is inhaled or ingested. Once inside the body, the alpha radiation can cause harm to individual cells or organs.

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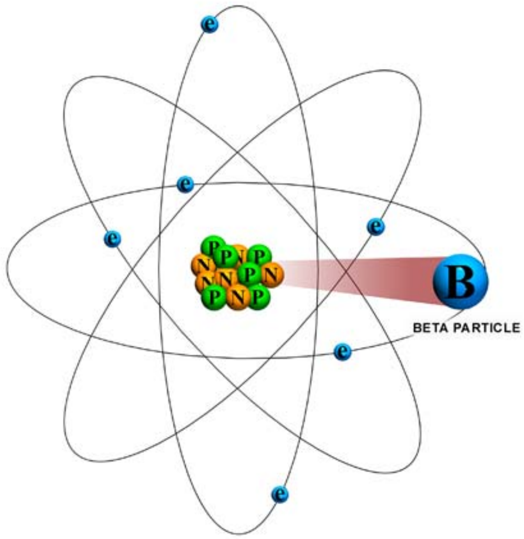
Beta



Beta radiation consists of particles that are smaller, lighter, and travel farther than alpha radiation. Because they are smaller and lighter, beta radiation is more penetrating than alpha radiation. The range of penetration in human tissue is less than ¼ inch. In air, beta radiation can travel several feet. Beta radiation may be blocked or shielded by plastic (SCBA face shield), aluminum, thick cardboard, several layers of clothing (bunker gear) or the walls of a building.

Outside the body, beta radiation constitutes only a slight hazard. Because beta radiation penetrates only a fraction of an inch into living skin tissue, it does not reach the major organs of the body. However, exposure to high levels of beta radiation can cause damage to the skin and eyes. Internally, beta radiation is less hazardous than alpha radiation because beta particles travel farther than alpha particles and, as a result, the energy deposited by the beta radiation is spread out over a larger area. This causes less harm to individual cells or organs.

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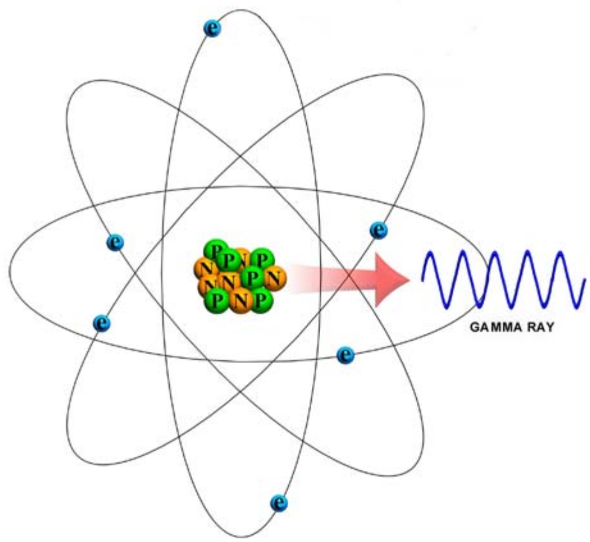
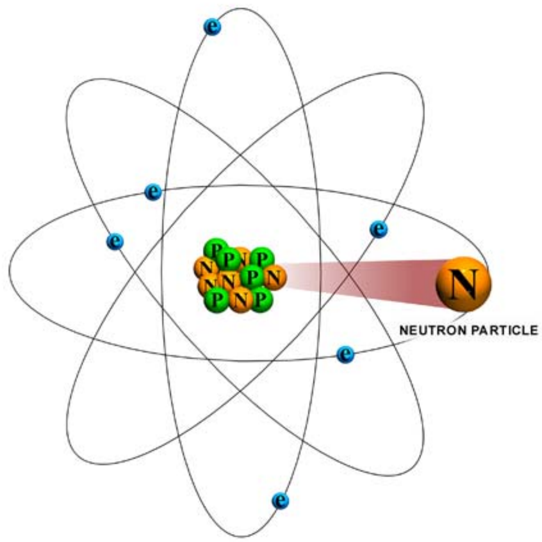
Gamma



Gamma radiation, like X-rays, is electromagnetic radiation. This means that it does not consist of particles like alpha and beta radiation but, rather, waves of energy that have no mass and no electrical charge. Because they have no mass and no electrical charge, they are able to travel great distances and require dense material as shielding. Gamma radiation poses a hazard to the entire body because it can penetrate human tissue. Lead, steel, and concrete are commonly used to shield gamma radiation.

Neutron



Neutron radiation consists of neutron particles that are ejected from an atom's nucleus. Neutron radiation can travel great distances and is highly penetrating like gamma radiation. It is best shielded with high hydrogen content material (e.g., water, plastic). In transportation situations, neutron radiation is not commonly encountered.

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TERMINOLOGY ASSOCIATED WITH RADIOACTIVE MATERIAL SHIPMENTS

Familiarity with terminology used for describing radioactive material in transport will help you function and communicate more effectively during a transportation incident involving radioactive material. The following terms are often associated with radioactive material shipments and may appear on shipping papers:

Fissile Material - material whose atoms are capable of nuclear fission (capable of being split). Department of Transportation (DOT) regulations define fissile material as plutonium-238, plutonium-239, plutonium-241, uranium-233, uranium-235, or any combination of these radionuclides. This material is usually transported with additional shipping controls that limit the quantity of material in any one shipment.

LSA - an acronym that stands for low specific activity. This means radioactive material with a limited amount of radioactivity in relationship to the total amount of material present. LSA generally applies to ores, mill tailings, contaminated earth, etc.

Special Form Radioactive Material - radioactive material which is either a single solid piece or a sealed capsule that can be opened only by destroying the capsule. During accident conditions, special form radioactive material would be non-dispersible and would therefore not present a contamination hazard. Though not a contamination hazard, special form sources may pose a significant radiation hazard. A sealed radioactive source used in radiography operations (like the one pictured below) is an example of a special form radioactive material.

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Normal Form Radioactive Material - any material that has not been demonstrated to qualify as "special form." Most radioactive material is shipped as normal form. Examples would include powders, liquids, etc.

SCO - an acronym that stands for Surface Contaminated Objects. SCO means a solid object that is not in and of itself radioactive but has radioactive material deposited on any of its surfaces (i.e., contamination). Examples of SCO material would include equipment (shovels, drills, etc.) used in decommissioning activities.

Transport Index (TI) - number used to designate the degree of control to be exercised by the carrier during transportation. In most cases, the transport index is equal to the maximum radiation level (measured in mrem/hr) at one meter (3.3 feet) from an undamaged package. TI appears on Radioactive Yellow II and III labels and on the shipping papers. The transport index can be used by the responder as a good starting point for determining whether damage has occurred to a package.

TERMINOLOGY ASSOCIATED WITH RADIOACTIVE WASTE

Many of the radioactive material shipments made in the United States are classified as radioactive waste. Four common types of waste and a description of each follows:

Transuranic Waste (TRU) - The DOE defines Transuranic Waste as material contaminated with certain isotopes of plutonium, and nuclides with atomic numbers greater than 92 (uranium), a half-life greater than 20 years, and concentrations greater than 100 nanocuries (100 billionth of a curie) per gram of waste material. It is produced primarily from reprocessing spent fuel and from use of plutonium in fabrication of nuclear weapons.

Low-level Radioactive Waste (LLW) - a general term for a wide range of wastes. Industries; hospitals; medical, educational, or research institutions; private or government laboratories; and nuclear fuel cycle facilities (e.g., nuclear power reactors and fuel fabrication plants) that use radioactive material generate low-level wastes as part of their normal operations. These wastes are generated in many physical and chemical forms with varying levels of contamination.

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High-level Radioactive Waste (HLW) - waste that consists of: irradiated (spent) reactor fuel; liquid waste resulting from the operation of reprocessing irradiated reactor fuel; and solids into which such liquid wastes have been converted. HLW is primarily in the form of spent fuel from commercial nuclear power reactors.

Mixed Waste - waste that contains both radioactive and hazardous chemical components.

COMMON RADIOACTIVE MATERIAL PROPER SHIPPING NAMES

Title 49 of the Code of Federal Regulations (CFR) is where many of the regulatory requirements for the transport of radioactive materials are found. Title 49 contains the Hazardous Materials Table (HMT), which categorizes material the DOT has designated as hazardous material for purposes of transportation. The HMT outlines requirements for shipping papers, marking, labeling, and transport vehicle placarding. For each material listed, the HMT provides information on the hazard class, the United Nations Identification Number (UN ID), gives the Proper Shipping Name, and other information for preparing hazardous material shipments.

The most commonly used Proper Shipping Names for radioactive material are listed below in Table 1. These Proper Shipping Names are also found in the blue pages of the ERG. Note that the words "radioactive material" appear as a part of the Proper Shipping Name for all material listed in Table 1. The Proper Shipping Names for less frequently encountered radioactive material, all of which have a comparatively low order of radioactivity but pose a secondary (subsidiary) hazard, are listed in Table 2. For these materials, where the words "radioactive material" is not a part of the Proper Shipping Name, the Code of Federal Regulations requires that the shipper include the words "radioactive material" on the shipping papers.

Table 1. Commonly Used Proper Shipping Names

Proper Shipping Name	UN ID
Radioactive material, articles manufactured from depleted Uranium	2909
Radioactive material, articles manufactured from natural Thorium	2909
Radioactive material, articles manufactured from natural Uranium	2909
Radioactive material, empty packages	2908
Radioactive material, excepted package, articles manufactured from natural uranium, depleted uranium or natural thorium	2909
Radioactive material, excepted package - empty packaging	2908
Radioactive material, excepted package, instruments or articles	2910
Radioactive material, excepted package, limited quantity of material	2910
Radioactive material, fissile, n.o.s.	2918
Radioactive material, instruments or articles	2911
Radioactive material, limited quantity, n.o.s.	2910
Radioactive material, low specific activity (LSA), n.o.s.	2912
Radioactive material, low specific activity (LSA-I)	2912
Radioactive material, low specific activity (LSA-II)	3321
Radioactive material, low specific activity (LSA-II), fissile	3324
Radioactive material, low specific activity (LSA-III)	3322
Radioactive material, low specific activity (LSA-III), fissile	3325
Radioactive material, n.o.s.	2982
Radioactive material, special form, n.o.s.	2974
Radioactive material, surface contaminated objects (SCO or SCO- I or SCO-II)	2913
Radioactive material, surface contaminated objects (SCO-I or SCO-II) fissile	3326
Radioactive material, transported under special arrangement	2919
Radioactive material, transported under special arrangement, fissile	3331
Radioactive material, Type A package	2915
Radioactive material, Type A package, fissile	3327
Radioactive material, Type A package, special form	3332
Radioactive material, Type A package, special form, fissile	3333
Radioactive material, Type B(M) package	2917
Radioactive material, Type B(M) package, fissile	3329
Radioactive material, Type B(U) package	2916
Radioactive material, Type B(U) package, fissile	3328
Radioactive material, Type C package	3323
Radioactive material, Type C package, fissile	3330
Radioactive material, uranium hexafluoride, fissile	2977
Radioactive material, uranium hexafluoride non-fissile or fissile excepted	2978

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Table 2. Less Frequently Encountered Proper Shipping Names for Radioactive Material by Chemical Name – Material Having a Subsidiary Hazard (All have a low hazard from radioactivity, but have a serious secondary hazard).

Proper Shipping Name	UN ID
Thorium metal, pyrophoric	2975
Thorium nitrate, solid	2976
Uranium metal, pyrophoric	2979
Uranyl acetate	9180
Uranyl nitrate hexahydrate solution	2980
Uranyl nitrate, solid	2981
Uranium hexafluoride, *fissile (containing more than 1 % U-235)*	2977
Uranium hexafluoride, *fissile excepted or non-fissile*	2978

Note: italicized text in table 2 is not a part of the Proper Shipping Name, but may be used on shipping papers in addition to the Proper Shipping Name.

RADIOLOGICAL UNITS

In 1975, the 15th General Conference of Weights and Measures adopted new names for certain basic units in radiation protection technology. These new units are consistent with the metric system or with the International System of Units (SI system) developed by the International Committee for Weights and Measures.

Measuring Radiation

The Roentgen (R) and Rem (Roentgen Equivalent Man)

Radiation exposure is measured in units of roentgen and rem. For our purposes, one roentgen is equal to one rem. Because one roentgen or one rem of radiation is a fairly large amount of radiation, the prefix milli is often used. Milli means one one-thousandth (1/1000). In other words, there are 1000 milliroentgens (mR) in one roentgen, or 1000 millirem (mrem) in one rem. A typical radiation dose from a medical x-ray is about 40 mrem.

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According to the National Council on Radiation Protection (NCRP), the average person is exposed to a dose of approximately 360 mrem per year from both man-made and natural sources (NCRP Report No. 93).

In this section, we focus on the traditional units for radiation measurement because they are still widely used in the response community. The SI unit for radiation exposure is the sievert. One sievert is equal to 100 rem.

Measuring Radioactivity

Radioactivity is measured in the number of nuclear decays or disintegrations that occur in a sample during a specific time. This is known as the activity of the sample. Activity is listed on radiation-warning labels and shipping papers. It is important to note that radioactivity, regardless of the source, is constantly decreasing by half during every "half-life."

The conventional unit of activity is the curie (Ci), which is 3.7×10^{10} or 37 billion (37,000,000,000) disintegrations per second (dps).

The SI unit for activity is the becquerel (Bq), which equals 1 dps. Both the curie and becquerel measure the same thing—activity. One curie is considered to be a large amount of activity, whereas one becquerel is a very small amount of activity.

Because the SI unit for activity is a very small unit, prefixes are often used to change the size of the unit. Many of the commonly used prefixes are shown in the table below.

Symbol	Prefix	Prefix Value	Example
K	Kilo	1 thousand, or 10^3	KBq = one thousand becquerel
M	Mega	1 million, or 10^6	MBq = one million becquerel
G	Giga	1 billion, or 10^9	GBq = one billion becquerel
T	Tera	1 trillion, or 10^{12}	TBq = one trillion becquerel

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You will see the term becquerel used on shipping papers and warning labels. Activity may also be expressed as a measure of its concentration or specific activity. Common terms for measuring specific activity are Ci/g (curies per gram) and Bq/kg (becquerels per kilogram). It is important to note that there is no direct relationship between activity and the physical quantity of material present. Very high activity material can come in very small packages. For example, one gram of cobalt-60 (commonly used in radiation therapy) has an activity of about 42 TBq or 42 trillion disintegrations per second. On the other hand, one gram of thorium-232 (the radioactive material found in some lantern mantles) has an activity of about 4 KBq or 4,000 disintegrations per second. Therefore, you would need to have well over 10 billion grams (23,000 pounds) of thorium-232 to equal the activity in one gram of cobalt-60.

Check Your Understanding

1. The four basic types of ionizing radiation are ______, _____, _______and ________.

2. _______ ________ is defined by DOT regulations as plutonium-238, plutonium-239, plutonium-241, uranium-233, uranium-235, or any combination of these radionuclides.

3. ________ form radioactive material is radioactive material which is either a single solid piece or a sealed capsule that can be opened only by destroying the capsule.

4. ___________ waste consists of material contaminated with certain isotopes of plutonium, and nuclides with atomic numbers greater than 92 (uranium).

5. In most cases, the _________ ______ is equal to the maximum radiation level (measured in mrem/hr) at 3.3 feet from an undamaged package.

6. The ________ and ____ are two units used to measure radiation exposure.

7. The SI unit for measuring radioactivity (activity) is the _________.

M E R R T T

ANSWERS

1. alpha
   beta
   gamma
   neutron
2. Fissile material
3. Special
4. Transuranic
5. transport index
6. roentgen
   rem
7. becquerel